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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 675

Contribution from the Forest Service
HENRY S. GRAVES, Forester

Washington, D. C. ▼ June 25, 1918

# RANGE PRESERVATION AND ITS RELATION TO EROSION CONTROL ON WESTERN GRAZING LANDS

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## CONTENTS



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## PURPOSE OF THE STUDY.

The aim of this bulletin is to show the relation between range preservation and erosion and its control on grazing lands in the West. It is true, perhaps, that topography, climate, and soil are the primary factors in determining erosion; but, on the lands under discussion, the combination of these factors with the vegetative cover is such that erosion is slight where the natural conditions have not been disturbed and may be made serious by any influence which upsets the balance established by nature. Grazing may become such a disturbing influence by changing or destroying the vegetative cover. Numerous instances are on record where serious erosion was unknown until the ground cover was largely destroyed. On the other hand, in localities where the destroyed vegetation has been reestablished, a few typical cases of which are pointed out in the body of the report, serious erosion has been stopped.

The data in the bulletin were obtained, for the most part, on the high summer range of the Manti National Forest in central Utah, where the conditions influencing erosion are similar to those prevailing on many of the mountain ranges in Utah, Wyoming, Idaho, Nevada, Arizona, and New Mexico, and to some extent in other western States.

To complete the study will require a number of years, but the data already available on the decrease in the productivity of the soil resulting from erosion, the increase in the difficulty of revegetating the lands as erosion and soil depletion advance, and the influence of range preservation in preventing destructive erosion are of so much importance that their publication, together with the accompanying recommendations, should stimulate closer observation on the part of those in charge of the range lands throughout the West and bring about improvements in the management of these lands, which, in view of the needs of the Nation, should not be deferred.

## DAMAGE CAUSED BY EROSION.

Every drop of rain that falls on more or less exposed soil has the power of removing soil particles, and with them the soluble salts essential to plant growth. Where the vegetative cover on a watershed has been largely destroyed the washing off of the surface soil may remove infinitely more decomposed vegetable matter and soluble plant food in a single season—indeed during one violent storm—than would be deposited by the decay of the vegetation in years. More than this, the resulting erosion, with its rush of water and débris, frequently ruins the lands where the débris is deposited and puts out of commission roads, trails, power plants, and other improvements. In many localities loss of property from this source has been appalling.

The greatest damage from erosion on range lands occurs where the areas have been badly overgrazed and the ground cover destroyed or seriously impaired. Before the ranges had been overstocked and the ground cover impaired, erratic run-off and erosion were practically unknown. After the breaking up of the vegetative cover in the early nineties, however, many streams originally of steady yearlong flow and teeming with trout became treacherous channels with intermittent flow through which the water from rainstorms was plunged, or rose and fell according to the size and frequency of the storms and carried so much sediment in the water that fish and similar life could not exist. (Pl. I, fig. 1.)

The damage is not confined merely to the decrease in the forage yield on the range lands eroded and to the silting over of adjoining agricultural land to which the torrential floods carried the débris;

the efficiency of the watershed in maintaining a permanent flow of irrigation water is greatly decreased.

The importance of preserving the upper few inches of soil on the high ranges, and with it the vegetative cover, in order to regulate the stream flow, to maintain indefinitely the forage crop for grazing, and incidentally to prevent destructive erosion, is not always fully appreciated by the stockman and farmer. This is more especially true in localities where there is not an ample supply of irrigation water.

In the belief that more water would find its way into the irrigation canals if the vegetative cover were appreciably thinned out, there has been a tendency in some localities toward destructive grazing. For instance, several sheep owners have expressed a desire to be permitted to graze Ephraim Canyon so closely as to pack the soil firmly and to decrease appreciably the present density of that vegetation. They believed that a large amount of the water that is returned to the air in the form of evaporation from the vegetation, as well as that held by the rich surface soil, would, by thinning out the ground cover, be made available for irrigation. While it is true that if a given canyon were grazed destructively more water would undoubtedly rush down the water channels, and as a result a greater acreage of farm land could possibly be irrigated in early spring, there would be less water for subsequent irrigation at a time when the crops were seriously in need of it. With the destruction of the vegetative cover not even the lands most advantageously situated would have the benefit of a continuous stream flow for subsequent waterings during the season when even a light irrigation might result in the production of at least an average crop. In addition an enormous acreage of choice farm land would be destroyed by sedimentation, to say nothing of the high cost of upkeep of the irrigation ditches themselves.

Most farmers and live-stock growers adjoining the National Forests who are dependent upon the watersheds within the Forests for their irrigation water are likewise dependent upon the cool summer ranges for the maintenance of their stock. To graze any portion of the range destructively defeats the necessary economic balance between the range and live stock, on the one hand, and the farm land and farm crops, on the other. Much of the agricultural land adjoining the National Forests is so remote from railroads as to make the live-stock industry a necessity in the economic harvesting and marketing of the farm crops. And aside from the loss of various public and private improvements as a result of torrential floods and sediment deposits, there would remain only a small amount of forage, mostly inferior, on the watershed after three or four seasons of

excessively heavy grazing. The farmer-stockman can not afford to do without this feed. The temporarily larger profits that might be derived from overgrazing would soon be offset by the somewhat more moderate but continued profits accrued from a stable stock industry in which the lands are grazed on the basis of a sustained yield.

If instead of grazing merely one canyon beyond its carrying capacity the entire forest unit, and, indeed, all forest land of irregular topography throughout the West were likewise grazed, untold injury to farm land and other property from destructive erosion and floods would result, a sustained stream flow would no longer exist on the watersheds, and there would be neither a normal supply of water for the irrigation of the adjoining farm lands nor of forage for the live stock on the extensive forest ranges. Without these productive elevated range lands upon which to summer the stock, homes on many farms could no longer be maintained; and it would not be long before the lands would revert to the original wild state.

Within the boundaries of the Manti National Forest of Utah there is a belt of approximately 47,000 acres of land along the east side of the divide which is badly depleted as a result of overgrazing and erosion, making necessary a regulation protecting the areas from grazing part of the year. Along the west side of the divide there is a similar belt of about the same acreage where erosion is also causing damage. These belts are practically timberless, and are of value chiefly as watersheds, from which stream flow for irrigation is supplied, and for the grazing resources which they afford. That these and similar eroded lands would originally support a cow or the equivalent in sheep on from one-third to one-fifth the acreage required at the present time is evidence of the enormous loss annually to the live-stock industry alone. The soil and plant foods on these already relatively unproductive lands continue to be carried away by the run-off following each storm; and the destruction, where well advanced, is sure to continue until preventive measures are fully established.

Typical instances of the damage caused by erratic run-off and erosion are well worth citing. On July 28, 1912, a rainstorm occurred at the head of Ephraim Canyon, on the Manti National Forest, within a belt of 2 miles and between elevations of 9,000 and 10,500 feet. There was no rain in the valley or on the mountain below, approximately, 8,000 feet. The storm of 0.41 of an inch of rain fell intermittently, but at no time with special violence, for a period of two hours. A flood of sufficient force developed to reach to the city of Ephraim, 10 miles below, covering the streets and some farm land, and filling the basements of buildings with mud and débris. Laden with silt, logs, vegetable matter, and, during the

most violent period, with rocks containing as much as 30 cubic feet of material, the flood destroyed wagon roads, trails, and water ditches.

Another typical example of flood and erosion occurred on July 30, 1912, when a flow of torrential violence originated at the head of Becks Canyon. A rain, amounting to 0.55 of an inch, the greater part of which fell within an hour, started at 11 a. m., and at 11.45 a. m. a flood was pouring out of a small side canyon which drains into Becks Canyon from an area of less than 1,500 acres, at an elevation of about 10,000 feet. This area is virtually treeless and is fan-shaped, the main drainage channel originating at the head of a steep canyon which drops into Becks Canyon at the rate of about 1,000 feet in less than a mile. The soil is of a clay-loam type, and, considering the area as a whole, is of fair depth, there being but little outcrop. The slopes are moderately gentle, and because of this fact the area had not been included in the adjacent one which was protected from grazing until late in the season. An examination after the flood showed that the soil had been very densely packed by grazing previous to the storm. The whole of this small watershed was well marked with gullies. The flood was not observed until it reached the mouth of the side canyon. Here it presented a front approximately 8 feet wide and 1½ feet high. The water was so infiltrated with sediment that it did not run but rolled over and over, picking up small rock and gravel. The flow increased to a front of from 10 to 25 feet wide and from 6 to 8 feet high. The velocity and force of the rolling mass down the steep slope were appalling. The main flow lasted approximately one hour, varying in volume as had the rain 30 minutes previous. Owing to the enormous deposits of débris, the course at the mouth of the channel changed three times. As the stream changed its course from one side to another enormous quantities of material were deposited only to be carried away later. At one time approximately 5,000 cubic feet of the bank was torn out in a few minutes as the old bed filled up with material from above. All these tons of soil, vegetable matter, and other material were carried down by the rushing water in less than two hours after the rain began to fall.

In addition to the direct loss of personal property, damage to the range itself in the way of decreased forage production and soil depletion has a most vital effect on a community. Such loss is seldom fully appreciated until the stockmen must, of necessity, limit the number of animals grazed on the lands. Following the action of a few destructive floods, the productivity of the grazing lands may be so decreased that only the more inferior drought-resistant plants will thrive. Where the farm lands, upon which supplemental winter feed is grown, are remote from shipping points, as is true of much

of the farm land adjacent to the National Forests, it is evident that the crops produced can not be marketed profitably except by feeding to live stock. Even where suitable shipping facilities exist the farm lands are of value chiefly in the production of winter feed for the live stock handled on the National Forest ranges. Thus the depletion of the range not only presupposes a decrease in the number of stock grazed but tends to unbalance the agriculture of the locality.

As the forage production on range lands is decreased as a result of erosion, the water available for irrigation purposes decreases. The surface soil, containing as it does the decomposed vegetable matter, is the chief absorbing and retaining agent of water. A series of tests to determine the water-holding power of soils at different depths was carried out by obtaining samples of a noneroded soil of limestone origin in the spruce-fir type at 10,000 feet elevation, the results of which were as follows: Water-holding capacity, from surface to a depth of 6 inches, 56.4 per cent; 6 to 12 inches, 46 per cent; and 12 to 24 inches, 32.4 per cent. The percentage of organic matter contained in the soil samples was 15.8, 11.3, and 6.8, respectively. Hence the amount of water these soils retained against the force of gravity is roughly in direct proportion to the amount of organic matter intermingled with the soil particles. In the absence of this rich spongelike soil surface, the water is readily carried away by gravity, and the stream flow for irrigation purposes is extremely erratic and available only for a short time following rainstorms. Obviously, it is often impossible for the farmer to avail himself of this flood water for irrigation purposes for at least two reasons—the water may assume torrential magnitude and carry with it so much sediment as not to warrant its use for irrigation purposes, or owing to its unexpected occurrence the farmer may not be able to make use of it.

## FACTORS DETERMINING THE AMOUNT OF ERRATIC RUN-OFF AND EROSION.

The foregoing pages are intended to point out briefly the extent, occurrence, and economic aspect of erratic run-off and erosion on range lands similar in conditions to those studied. In order to be able to offer rational recommendations as to methods of prevention and control, however, it was necessary to study more in detail the factors involved. This has been accomplished by the selection and study of two areas where floods of unusual violence have originated at various times.

In the spring of 1912 two areas, designated as A and B, as similar as possible in topographic, soil, and climatic conditions and vegetation, were selected for the study. (See fig. 1.) The areas are located in the Manti National Forest at the head of Ephraim Canyon, on the

rim of the Wasatch divide, where fan-shaped drainage basins are characteristic.

Practically all the torrential floods which are responsible for the most serious destruction of property originate near the heads of the watersheds, usually at high altitudes. On the Manti Forest the most vital part of the watershed is that lying between altitudes of about 9,000 to 10,500 feet, within what is known as the spruce-fir type.


FIG. 1.—Erosion areas A and B, head of Ephraim Canyon, Manti National Forest, Utah.

It is on these elevated lands that the rainstorms are the heaviest and most violent, the slopes are steepest, and conditions in general most favorable to erosion.

The greater part of this upper mountain region consists of large fan-shaped basins which drain through narrow canyons into the valleys below. These canyons are relatively short and have a steep grade. Ephraim Canyon, for example, has an average grade of about 22 per cent, or approximately 1,160 feet to the mile. So rapid is

the drainage of water from these high basins that, in rushing through to the steep canyons, relatively little of the rain is absorbed by the soil; most of it plunges into the valleys below. Obviously, therefore, if the run-off from such areas is to be properly controlled, steps must be taken to maintain the soil cover. Unfortunately, it is these very basins that have been damaged most from overgrazing, consequently the soil and the ground cover are in the worse condition. Originally they supported a superb lot of feed especially suited to sheep, and being less broken in topography, less brushy, and more easily accessible than other parts of the range, generally they were the areas most sought for.

As is shown by the accompanying topographic and type map of the selected areas, A and B (fig. 1), seven rather distinct plant associations occur, viz: Yarrow-needlegrass-cinquefoil; yarrow-Douglas knotweed; adder's tongue-larkspur-sweet sage; currant-gooseberry-yarrow; bluegrass-wheatgrass-needlegrass (semi-scabland); giant larkspur-blue foxglove-Douglas knotweed; and yellow bush-sweet sage-peavine. The density of each of these associations is shown on the map. Most of the species are valuable as forage and as soil binders.

The soil is of limestone and sandstone origin, though chiefly the former, and varies in depth from a few inches to several feet. While there is some outcrop on both areas, the soil for the most part is fairly well decomposed. The principal drainage channels vary from 2 to 9 feet deep. In many places wherever a vegetative cover is lacking rills occur, though most of these are less than a foot in depth.

Although the two areas, as stated, are as nearly comparable as could be selected locally, yet several dissimilarities as to soil, slope, drainage, and vegetative cover occur, which occasion a much greater run-off from area A than from area B, other factors being equal. First, as shown in figure 1, area B has a vegetative cover exceeding that on area A by a density of 20 per cent. Accordingly, the soil on area B is bound together much more firmly by the plant roots than that on area A; the erosion is in a less advanced stage; and the greater amount of organic matter makes possible a greater absorption and retention of the rainfall. Area A, on the other hand, with its steeper slope lacks vegetation most where the greatest slope occurs and this tends greatly to increase run-off. Finally, area A has a different type of drainage system from area B. In cross section area A is broadly V-shaped and the main drainage is confined to one large channel running lengthwise through the area. Area B, on the other hand, is relatively flat in cross section and the drainage is divided among three principal channels. Naturally, there is more resistance to run-off which is distributed over the drainage than to run-off

thrown together into a single channel, as on area A, where the force of the water is accumulative. Thus the sum of conditions favor a larger run-off from area A than from area B. There is no permanent stream on either area, and run-off occurs only after rainstorms or from melting snow.

### MELTING SNOW.[1]

The accumulation of the winter snows of 1915–16 showed a water equivalent of 9.1 inches on area A and 9.2 inches on area B. This represents approximately 326,800 cubic feet of potential water on each of the 10-acre areas awaiting the spring thaw. What becomes of the water from the melting of this snow? The water registers show that 292,998 cubic feet ran off area A, while only 42,216.8 cubic feet ran off area B. This difference in run-off is due to the fact that the soil on area B contains more organic matter and has a better ground cover than area A. A small part of the snow water, of course, evaporates into the air, but the greater portion of that not accounted for in surface run-off is absorbed by the soil. Part of the water that percolates into the soil finds its way to the main drainage channels and serves as irrigation water in the valley below; the remainder becomes an important factor in the promotion of growth of range forage. The run-off occasioned by the melting of the snow accumulated in 1915–16 caused the removal of 172 cubic feet of soil from area A as against 82 cubic feet from area B.

As might be expected, there is less sediment per cubic foot of run-off from melting snow than from summer rainstorms. Further, the total amount of sediment brought down is less than that deposited by the single rainstorm of July 21, 1915, although the stream flow from the melting snow was approximately seven times greater.

[1] In order that the water, both from melting snow and from rainstorms, which flows from the areas may not escape through lateral rills and the record of stream flow be thus impaired, the gullies along the sides of the areas have been dammed. In order to measure accurately the run-off and sediment, a settling tank of adequate size, provided with weir and water register, has been installed at the lowest drainage point on each area. The amount of sediment deposited from each individual rainstorm and from the melting of the season's accumulation of snow is determined on the basis of the dry weight.

Owing to the intimate relation existing between run-off and erosion and certain climatic factors, the more important features are recorded throughout the year. Two standard rain gauges have been placed on each area. In addition, a tipping bucket rain gauge, located midway between the two erosion areas, records the amount and duration of each storm, as well as the rapidity of the rainfall. Snowfall measurements are taken at regular intervals of from 7 to 10 days throughout the winter season. In the spring before thawing occurs a detailed snow survey is again made. In this way the annual and the monthly precipitation on each area are known and the intensity and duration of the individual rainstorms accurately recorded.

The temperature and wind velocity are recorded by means of the thermograph and the anemometer, respectively, in the usual way. Temperature, like precipitation, is taken throughout the year, while the wind velocity is recorded only during the main growing season.

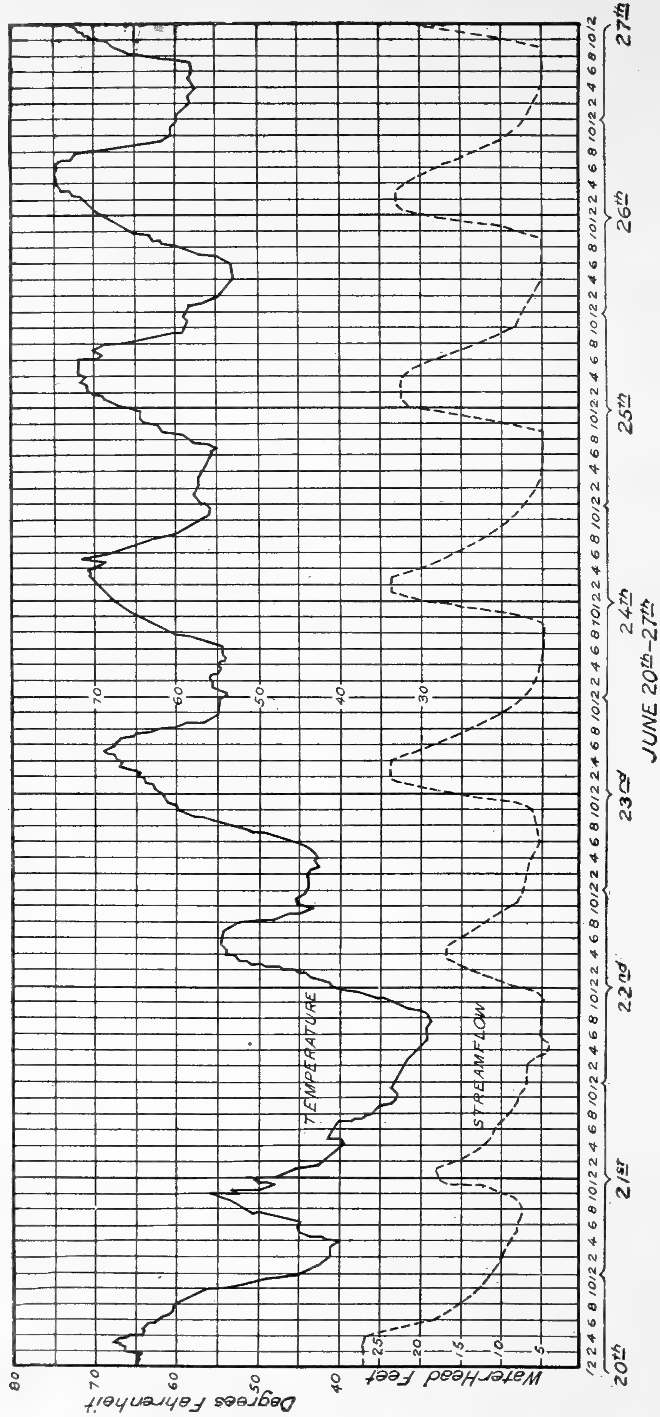



FIG. 2.—Relation of run-off from melting snow to temperature.

In correlating the meteorological data with stream flow from melting snow it was found that the stream flow follows very closely the fluctuations in temperature. The relative behavior of these factors is shown in figure 2. The flow increases with the rising temperature of the day and reaches the maximum at practically the same time that the mercury is at the highest point. The flow practically ceases between 8 p. m. and 10 p. m. and remains practically at zero during the cooler hours of the night, only to rise again with the increased temperature of the following day. High winds are found greatly to increase the rate of evaporation of the snow cover, but they affect the run-off relatively little.

Any medium, such as an effective vegetative cover, which serves to insulate the heat from the snow cover, breaks the effect of high, dry winds, and at the same time intercepts the run-off more or less, will tend to conserve the snow, regulate run-off, and make possible the absorption of a larger amount of water. This fact has been demonstrated on the wooded portion of the selected areas as well as on the extensively denuded, sparsely vegetated, and timbered lands on the forest generally.

To sum up the facts concerning the action of melting snow: Erosion from melting snow is a more serious factor than generally supposed when the vegetative cover is sparse and the slope steep. Both run-off and erosion from melting snow vary in intensity more or less directly with the character of certain climatic factors, especially temperature. In general, the soil is not frozen under a cover of a few inches of snow if the latter falls before cold weather early in the winter; so whenever melting takes place erosion may occur unless the soil is held firmly in place. The most rapid melting of snow and the most serious erosion occur where there is a lack of vegetation. In general, snow lies the longest on timbered lands.

## RAIN.

An examination of the accompanying tables showing rainfall and the resulting run-off, or lack of it, disclosed several interesting facts. In the first place, out of the 26 rainstorms for the year 1915 (Tables 1, 2, 3), distributed over the four months from June to September, inclusive, only one storm—that of July 21—produced run-off. At this time, according to the record of the four rain gauges, 0.70 and 0.71 of an inch of rain fell on area A and 1.48 and 1.38 on area B, within a period of 65 minutes. From area B the run-off was 335 cubic feet and it carried 94 cubic feet of air-dry sediment, as compared to 3,019 cubic feet of run-off on area A and 717 feet of air-dry sediment (fig. 3). It should be kept in mind that the run-off from area A was enormously greater than on area B in spite of the

fact that area A received less than one-half as much rainfall as area B.

The other 25 rainstorms of the year 1915, with the possible exception of one or two in June, produced no run-off, because they were of a much gentler nature, so that the soil was able to absorb the moisture as it fell. Exception is made to certain storms occuring during June, since there was at that time a continual flow from the melting

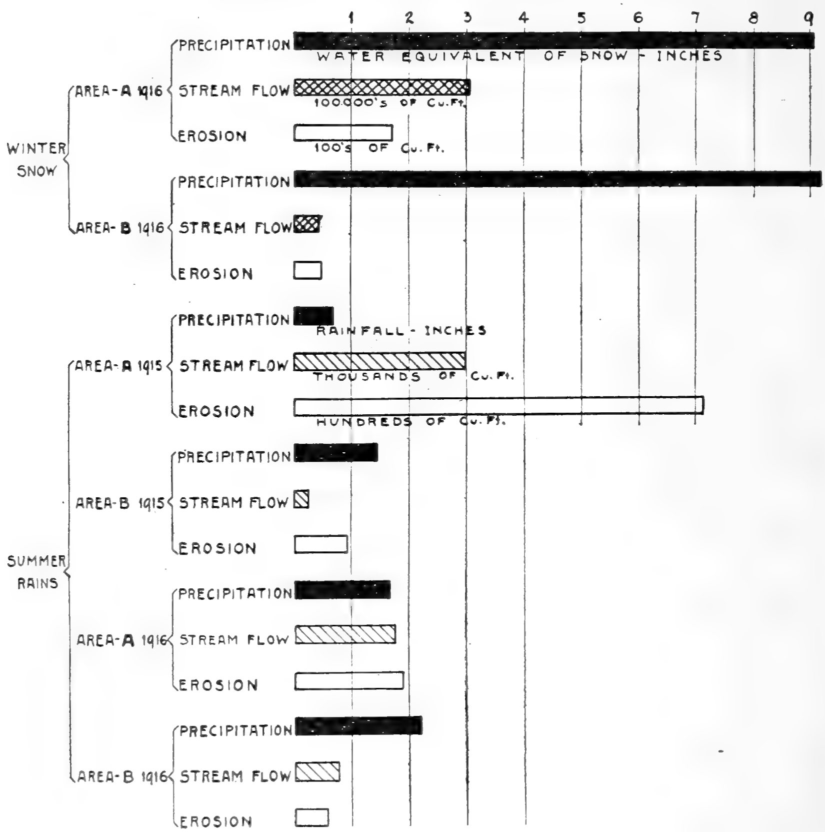



FIG. 3.—Erosion and run-off from melting of accumulated winter snow and from rainstorms.

of snow on the areas. The effect of rainfall upon the stream flow during the presence of melting snow could not be ascertained.

On July 4 a fall of 0.36 and 0.34 of an inch, respectively, were recorded from the two rain gauges on area A, and 0.43 and 0.40 of an inch on area B, over a period of 3 hours and 25 minutes. This resulted in no run-off. On September 2 and 3 there was a fall of 0.65 and 0.65 of an inch on area A and 0.62 and 0.63 of an inch on area B, covering a period of 8 hours and 45 minutes. This produced no run-off. These latter two cases, in which the rain fell at an

average rate of from 0.08 to 0.10 of an inch per hour, represent the rapidity of rainfall characteristic of the storms throughout the season. As a rule, storms as mild as this have little effect in causing run-off or erosion.

During the rainy reason of 1916 conditions were somewhat different from those of 1915. There were several storms covering periods of from two to five days successively. Naturally, storms of such duration have a greater effect in causing run-off than short mild storms. It was found that the rain for a time, depending upon the prior condition of the soil as to dryness and compactness, was absorbed and there was no surface run-off whatever; but after the soil became completely saturated and the rainfall still continued, run-off occurred and with it was carried a large amount of sediment. (Pl. I, fig. 1.)

TABLE 1.—*Rainfall on erosion areas, season 1915.*

| Date. | Area A. | | Area B. | |
|---|---|---|---|---|
| | Upper gauge. | Lower gauge. | Upper gauge. | Lower gauge. |
| June 1 | 0.75 | 0.75 | 0.75 | 0.75 |
| June 2 | .25 | .25 | .25 | .25 |
| June 3 | .12 | .12 | .12 | .12 |
| June 6 | .95 | .95 | .95 | .95 |
| June 9 | .02 | .02 | .02 | .02 |
| June 13 | .03 | .03 | .03 | .03 |
| | 2.12 | 2.12 | 2.12 | 2.12 |
| July 4 | .36 | .34 | .43 | .40 |
| July 21 [1] | .70 | .71 | 1.48 | 1.38 |
| July 23 | .04 | .04 | .04 | .04 |
| July 24 | .10 | .10 | .09 | .10 |
| July 25 | .15 | .13 | .12 | .12 |
| July 26 | .07 | .07 | .07 | .07 |
| July 27 | .11 | .11 | .11 | .11 |
| | 1.53 | 1.50 | 2.34 | 2.22 |
| Aug. 5 | .01 | .01 | .01 | .01 |
| Aug. 6 | .10 | .08 | .09 | .01 |
| Aug. 14 | .01 | .01 | .01 | .01 |
| Aug. 16 | .22 | .20 | .14 | .16 |
| Aug. 24 | .02 | .02 | .02 | .02 |
| | .36 | .32 | .27 | .30 |
| Sept. 2 | .15 | .15 | .13 | .13 |
| Sept. 3 | .65 | .65 | .62 | .63 |
| Sept. 4 | .11 | .12 | .10 | .09 |
| Sept. 7 | .05 | .05 | .05 | .05 |
| Sept. 8 | .26 | .21 | .32 | .27 |
| Sept. 11 | .18 | .18 | .18 | .18 |
| Sept. 13 | .03 | .03 | .02 | .02 |
| Sept. 25 | .39 | .29 | .36 | .44 |
| Total | 1.82 | 1.68 | 1.78 | 1.81 |
| Total for the four months | 5.85 | 5.62 | 6.51 | 6.45 |
| Average | 5.79 | | 6.48 | |

[1] This was the only storm of the season to produce run-off.

TABLE 2.—*Precipitation record on erosion areas, 1916.*

| Character of precipitation. | Duration of storm. | | | | | | Area A. | | Area B. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Beginning. | | | Ending. | | | | | | |
| | Month. | Day. | Hour. | Month. | Day. | Hour. | Upper gauge. | Lower gauge. | Upper gauge. | Lower gauge. |
| Snow, 4 inches. | May | 20 | 8.30 a.m. | May | 20 | 1.00 p.m. | 0.84 | 0.93 | 0.58 | 0.59 |
| Snow, 2 inches. | June | 21 | 10.00 p.m. | June | 22 | 3.00 a.m. | .01 | .01 | Trace. | .01 |
| Rain | July | 7 | 6.30 p.m. | July | 7 | 9.30 p.m. | .06 | .06 | .06 | .06 |
| Do | do | 8 | 2.00 p.m. | do | 8 | 3.30 p.m. | .04 | .03 | .03 | .02 |
| Do | do | 9 | 3.30 p.m. | do | 9 | 5.00 p.m. | .03 | .03 | .03 | .02 |
| Do | do | 14 | 6.30 a.m. | do | 14 | 1.30 p.m. | .07 | .09 | .11 | .09 |
| Do | do | 15 | 12.00 m. | do | 15 | 2.30 p.m. | .12 | .13 | .10 | .10 |
| Do | do | 16 | 10.30 a.m. | do | 16 | 12.00 m. | .31 | .36 | .32 | .32 |
| Do | do | 21 | 7.15 p.m. | do | 21 | 8.30 p.m. | .16 | .16 | .16 | .17 |
| Do | do | 24 | 12.45 p.m. | do | 24 | 5.45 p.m. | .27 | .27 | .27 | .27 |
| Do | do | 25 | 8.15 a.m. | do | 25 | 2.45 p.m. | .30 | .30 | .30 | .30 |
| Do | do | 26 | 7.45 a.m. | do | 26 | 9.15 a.m. | .16 | .12 | .39 | .31 |
| Do | do | 26 | 4.30 p.m. | do | 26 | 5.00 p.m. | .07 | .07 | .08 | .08 |
| Do | do | 27 | 6.15 a.m. | do | 27 | 6.45 a.m. | .06 | .07 | .07 | .07 |
| Do | do | 27 | 11.30 a.m. | do | 27 | 4.00 p.m. | .15 | .15 | .25 | .20 |
| Do | do | 31 | 12.55 p.m. | do | 31 | 1.40 p.m. | .10 | .14 | .16 | .15 |
| Do | August | 1 | 4.05 p.m. | August | 1 | 6.30 p.m. | .04 | .04 | .04 | .04 |
| Do | do | 2 | 11.40 a.m. | do | 2 | 12.00 m. | .29 | .32 | .38 | .39 |
| Do | do | 2 | 9.45 p.m. | do | 2 | 10.45 p.m. | .15 | .16 | .28 | .24 |
| Do | do | 3 | 11.15 a.m. | do | 3 | 11.25 a.m. | .04 | .04 | .09 | .06 |
| Do | do | 4 | 1.00 p.m. | do | 4 | 2.30 p.m. | .09 | .08 | .10 | .09 |
| Do | do | 5 | 12.20 p.m. | do | 5 | 3.40 p.m. | .25 | .25 | .28 | .27 |
| Do | do | 7 | 11.50 a.m. | do | 7 | 1.00 p.m. | .05 | .05 | .06 | .05 |
| Do | do | 7 | 6.35 p.m. | do | 7 | 6.45 p.m. | T. | T. | .01 | .01 |
| Do | do | 12 | 11.10 a.m. | do | 12 | 10.30 p.m. | .55 | .57 | .54 | .53 |
| Do | do | 16 | 6.45 a.m. | do | 16 | 10.00 a.m. | .07 | .07 | .08 | .06 |
| Do | September | 2 | 1.40 p.m. | September | 2 | 4.00 p.m. | .12 | .12 | .13 | .12 |
| Do | do | 8 | 2.15 p.m. | do | 8 | 4.10 p.m. | .10 | .08 | .13 | .11 |
| Hail | do | 9 | 7.30 a.m. | do | 9 | 10.15 a.m. | .14 | .17 | .18 | .12 |
| Snow | do | 22 | 5.00 p.m. | do | 22 | 10.30 p.m. | .15 | .14 | .17 | .15 |
| Rain and snow | do | 30 | 11.00 p.m. | October | 1 | 4.00 a.m. | .45 | .52 | .61 | .64 |
| Snow | October | 6 | | | | | .83 | .83 | .83 | .83 |
| Do | do | 10 | | | | | .48 | .48 | .48 | .48 |
| Do | do | 11 | | | | | .06 | .07 | .06 | .07 |
| Do | do | 15 | | | | | .64 | .87 | .64 | 87 |
| Do | do | 20 | | | | | .17 | .20 | .17 | .20 |
| Total | | | | | | | 7.42 | 7.98 | 8.17 | 8.09 |
| Average | | | | | | | 7.70 | | 8.13 | |

TABLE 3.—*Erosion and run-off records, 1915 and 1916.*[1]

| Area. | Date. | Character of storm. | Precipitation. | Run-off. | Erosion. |
|---|---|---|---|---|---|
| | | | *Inches.* | *Cubic feet.* | *Cubic feet.* |
| A | July 13, 1915 | Winter snows | (²) | (²) | 230.91 |
| B | June 29, 1915 | do | (²) | (²) | 184.82 |
| A | July 21, 1915 | Rain | 0.70 | 3,018.96 | 716.92 |
| B | do | do | 1.43 | 335.15 | 94.29 |
| A | July 8, 1916 | Snow | 9.10 | 292,998.19 | 172.36 |
| B | June 15, 1916 | do | 9.20 | 42,216.75 | 82.62 |
| A | July 16, 1916 | Rain | .34 | 114.76 | 8.45 |
| A | July 24, 1916 | do | .27 | 100.80 | |
| A | July 26, 1916 | do | .14 | 86.40 | |
| A | do | do | .07 | 108.00 | 19.30 |
| A | July 27, 1916 | do | .06 | 41.76 | |
| A | do | do | .15 | 86.40 | |
| A | Aug. 2, 1916 | do | .30 | 608.68 | 105.54 |
| B | do | do | .38 | 257.15 | 26.34 |
| A | do | do | .15 | 37.44 | 4.54 |
| B | do | do | .26 | 80.62 | 8.93 |
| A | Aug. 5, 1916 | do | .25 | 589.96 | 56.52 |
| B | do | do | .27 | 439.40 | 24.54 |
| A | Oct. —, 1916 | Rain and snow | 2.32 | 492.48 | 3.14 |
| B | do | do | 2.32 | 58.38 | 0.00 |

[1] Only those rainstorms that produced stream flow are here given. Note that several storms produced run-off on area A but not on area B.
[2] No records.

A significant feature to be noted from the 1916 precipitation and run-off records is the fact that run-off occurred on area A as a result of storms that produced no flow from area B, in spite of the fact that area B received just as much or generally more rain than area A. Surface conditions again account for this fact.

Table 4 summarizes the rainfall for the two years 1915 and 1916 and the resulting erosion and run-off. It shows the comparative effects of gentle storms and storms of unusual violence, such as not infrequently occur in the higher mountain region of the Manti Forest. From Table 4 it is apparent that of the summer rains of 1916, totaling 7.70 inches on area A and 8.13 inches on area B, 14 storms on area A and 8 on area B were effective in producing run-off. In 1915 there was but one such storm, yet the erosion from this single storm was very much greater than from the several storms of 1916. The most significant fact shown is that the per cent of sediment carried in the run-off is proportionately higher as the velocity of the flow increases. Thus if we apply the established formula, namely, that the transporting power varies directly as the sixth power of its velocity, it is evident that if the velocity of a flow is increased two times its transporting power is increased 64 times. It is understood too, of course, that the larger the flow the greater is the velocity of that flow.

To sum up, the extent of erosion and run-off depends upon (1) the rate at which the rain falls, (2) the steepness of the slope, (3) the presence of well-established gullies, (4) the character of the soil, and (5) the density and character of the vegetation.

TABLE 4.—*Run-off and erosion from rainstorms.*

| Year. | Area. | Total number of storm days. | Total rainfall. | Effective[1] storm days. | Effective[1] rainfall. | Run-off. | Sediment. | Sediment. |
|---|---|---|---|---|---|---|---|---|
| | | | | | *Inches.* | *Cubic feet.* | *Cubic feet.* | *Per cent.* |
| 1915 | A | 26 | 5.79 | 1 | 0.70 | 3,018.96 | 716.92 | 23.70 |
| 1915 | B | 26 | 6.48 | 1 | 1.43 | 335.15 | 94.29 | 28.13 |
| 1916 | A | 36 | 7.70 | 14 | 4.05 | 2,266.68 | 197.49 | 8.70 |
| 1916 | B | 36 | 8.13 | 8 | 3.23 | 835.55 | 59.81 | 7.20 |

[1] Effective here refers to storms that produced run-off.

## WIND.

In addition to the conspicuous action of the gully or shoe-string type of erosion described above, erosion caused by the action of the wind more or less uniformly over the soil surface is a factor of high importance in determining the fertility of the soil under certain conditions.

Following the destruction of the vegetative cover, either entirely or in part, the wind movement becomes particularly active in the

translocation of soil. In practically all regions wind is sufficiently strong to cause soil particles, not firmly bound by vegetation, to be carried from one place to another and subsequently to be transported downward by water. On elevated lands enormous quantities of soil are often carried away, not uncommonly causing uniform removal of several inches of the surface soil (Pl. I, fig. 2). This is in part due to the sparseness of the vegetative cover, especially of tree growth, and its failure to break the wind. On the more elevated lands the vegetation is usually less dense than at lower altitudes, so that the wind has considerable more effect and its velocity is considerably greater, as Table 5 shows.

TABLE 5.—*Monthly wind movement in miles in the spruce-fir type (elevation 10,000 feet) and in the aspen type (elevation 8,500 feet).*

| Month. | Year. | Aspen. | Spruce-fir. |
|---|---|---|---|
| | | *Miles per month.* | *Miles per month.* |
| June | 1915 | 3,081 | 6,501 |
| | 1916 | 3,020 | 7,119 |
| July | 1915 | 3,055 | 6,807 |
| | 1916 | 3,697 | 5,505 |
| August | 1915 | 3,339 | 4,836 |
| | 1916 | 3,198 | 5,116 |
| September | 1915 | 3,008 | 7,632 |
| | 1916 | 3,080 | 6,873 |
| Total | 1915 | 12,483 | 25,776 |
| | 1916 | 12,995 | 24,613 |

Considering the two locations month by month for the period given, it is evident that the wind movement during the growing season, which is practically the only time when the soil is exposed and subject to wind erosion in the higher type, is approximately 100 per cent greater in the heart of the spruce-fir type at 10,000 feet elevation than in the aspen type 1,500 feet below.

In order to show more in detail the periodic behavior of the wind during the season when the soil is exposed and subject to movement by the wind, the maximum and average wind velocities recorded in 1916 have been summarized by 10-day periods. The results are given in Table 6.

TABLE 6.—*Maximum and average wind velocities (miles per hour) summarized by 10-day periods, season 1916.*

| Type. | Wind. | June. | | | July. | | | August. | | | September. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1-10 | 11-20 | 21-30 | 1-10 | 11-20 | 21-30 | 1-10 | 11-20 | 21-30 | 1-10 | 11-20 | 21-30 |
| Aspen, elevation 8,750 feet | Maximum | 13 | 9 | 9 | 20 | 18 | 17 | 17 | 14 | 10 | 14 | 12 | 12 |
| | Average | 4.5 | 5.9 | 4.1 | 5.1 | 4.2 | 5.6 | 5.0 | 4.3 | 3.7 | 5.0 | 3.8 | 4.0 |
| Spruce-fir, elevation 10,000 feet | Maximum | 27 | 26 | 24 | 17 | 18 | 12 | 21 | 22 | 19 | 34 | 16 | 33 |
| | Average | 10.3 | 9.3 | 9.6 | 8.2 | 7.3 | 7.1 | 9.5 | 8.2 | 6.7 | 12.5 | 6.6 | 9.9 |

FIG. 1.—UNDERMINING OF EPHRAIM CREEK DURING A TORRENTIAL FLOOD.

Following practically every rainstorm causing erratic run-off of any consequence, parts of Ephraim Creek, near the foot of the mountain where the force of the water is greatest, are undermined and the banks cave in. Most of the loosened silt and rocks are carried down to the valley by subsequent storms.

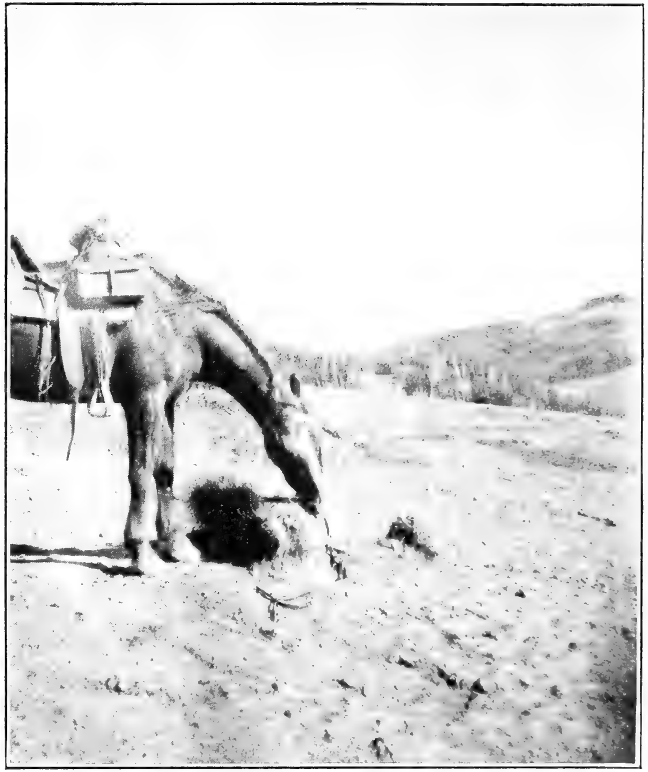


FIG. 2.—RANGE LAND STRIPPED OF ITS GOOD SOIL.

The remaining grass hummocks mark the depth to which the rich surface soil has been removed in a sheet by wind and water erosion.

RESULTS OF SHEET AND WIND EROSION NEAR TIMBER LINE.

The protective vegetation has been partly removed and the fertility of the soil so seriously impoverished by erosion that few species of plants are hardy enough to establish themselves. It will require decades to revegetate such lands thoroughly.

The above summations show clearly that the maximum velocity of wind in the spruce-fir type exceeds by about 200 per cent that in the aspen type at certain periods. These gales on the elevated plateaus, especially where the ground cover is sparse, have a marked effect on the movement of the soil and without doubt are an important factor in causing erosion when the surface soil is dry and exposed (Pl. II). It is especially important, therefore, that the vegetable cover on these elevated lands be maintained in a maximum state of density in order to bind the soil firmly.

## VEGETATIVE COVER.

While the foregoing data indicate that the extent of surface run-off and erosion are determined by the combined action of a number of factors, the vegetative cover is the most important single controllable factor under the conditions in question. Man has little control over climate and topography, and improvement in soil conditions most favorable to the control of erosion on the range lands under discussion must be accomplished chiefly through the improvement in the vegetative cover. Even this possibility of control is limited primarily to what can be accomplished by management of the lands so as to favor the development of the native vegetation to the greatest possible extent because western range conditions in general are not favorable to the planting of cultivated species. This importance of the native vegetative cover in maintaining conditions unfavorable to erosion may be considered both a drawback and an advantage, for, on the one hand, certain precautions must be taken in harvesting the forage crop in order to preserve and maintain the vegetation; but on the other hand, there are relatively few lands which, under proper management, can not be revegetated enough so that serious erosion and destructive floods may be prevented.

Anybody on a virgin or completely vegetated range during a heavy rainstorm can not fail to notice to what a great extent the vegetation, whether grass, weed, browse, or timber, protects the soil and increases its power of soaking up the water. Instead of the entire force of the rain falling on an unprotected and exposed soil surface, as in the absence of vegetation, the rain is intercepted more or less by the vegetation, so that by the time the water reaches the soil surface its original force is broken. There are several reasons why a well vegetated surface offers the best condition for absorption and underground storage of water. The foliage and stems of the vegetation form a storage place from which water drips slowly to the ground for considerable time after each rain; and the leaves and stems, in a more or less advanced stage of decay, absorb mois-

ture with each heavy rain and tend to hold the water back. The records taken on the selected areas in connection with the run-off and erosion from melting snow showed clearly that the snow lies longer under a vegetative cover than in the open, and more water is therefore available for absorption by the soil in the spring of the year in the presence of a good plant cover. Aside from the vegetation protecting the snow from the direct rays of the sun, the roots create minute channels for the ready entrance of water into the earth. To destroy this vegetative cover as shown in Plate III, then, is to decrease materially the power of absorption of the soil.

The soil on fully vegetated lands contains a much larger amount of organic matter than on denuded areas and this greatly increases both the water-holding capacity of the soil and its power of absorption. Accordingly, on fully vegetated lands there is practically no erosion except during violent rainstorms of short duration or after prolonged heavy rains, and even then the erosion is seldom serious. On denuded or sparsely vegetated slopes, on the other hand, run-off and erosion may occur after very small rainstorms.

## RELATION OF EROSION AND SOIL DEPLETION TO VEGETATIVE GROWTH.

It has long been known that different plant species may exhibit a great difference in the amount of water required in various soils to produce a unit of dry matter, a function of profound economic importance in the agricultural development of a region of limited rainfall. Carefully conducted experiments have also proved that when certain fertilizers are added to a soil lacking in plant foods the amount of water evaporated from a plant in the production of a unit of dry matter is considerably reduced, and that the stand of vegetation may be dense or sparse according to the fertility of the soil.

In view of these facts, it seemed probable that the sparseness of the native vegetation generally observed on lands whose soils have been subject to more or less serious washing and leaching for a number of years, the short stature of the plants, and the virtual lack of seed production, might be accounted for by the low fertility of the soil and lack of sufficient moisture coupled with a relatively high water requirement of the vegetation in the production of growth.

In order to determine the difference, if any, in the potential crop production and water requirement of plants grown on eroded and noneroded soils, samples of identical origin and type were selected for comparative study. The soils in question were selected in the spruce-fir type on typical summer sheep range at approximately 10,000 feet elevation. After being carefully sifted and thus freed of the larger pebbles, etc., the soils were moistened moderately and

tamped firmly in cans 14 inches wide and 17 inches high. Six large test pots were used, three of which contained eroded and three noneroded soil, and each was planted to five seedling plants as follows: One set, consisting of one pot of eroded and one of noneroded soil, to a pedigreed field pea known as Kaiser variety; one set to native bromegrass, locally called wild oats (*Bromus marginatus seminudus*); and the third set to a pedigreed wheat known as Kubanka No. 1440.

The pots were hermetically sealed and so arranged that all the water loss from the soil had to pass through the plants in the form of transpiration or evaporation. The pots were weighed at regular intervals and water was added to the soil so that the moisture content was kept practically constant. Throughout the experiment the average moisture content was about 30 per cent, a supply ample to produce the most vigorous growth on both soil types.

Owing to the action of the elements on the two soils studied there was an interesting and significant difference both in their chemical and physical properties. The percentages of salts important to the growth and development of plants in these soils are as follows:

TABLE 7.—*Salts important to the growth and development of plants on the two soils studied.*

| Soil. | Lime (CaO). | Potash ($K_2O$). | Phosphoric acid ($P_2O_5$). | Total nitrogen. | Loss on ignition (humus). |
|---|---|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* | *Per cent.* |
| Eroded | 1.26 | 1.53 | 0.22 | 0.156 | 6.64 |
| Noneroded | 1.49 | 1.30 | .33 | .488 | 14.65 |

In all the constituents considered except potash, the noneroded soil is much the richer. The greatest difference is found in the total nitrogen content, one of the most important of plant foods. This is due to the fact that a large proportion of the nitrogen compounds are more or less soluble in water and consequently had been largely washed out of the eroded soil.

The chief physical properties are those which affect the total water-holding capacity of the soils and the amount of water that can be absorbed from them by a plant. These properties are intimately associated with the amount of organic matter in the soils. The eroded soil was found to have a maximum water-holding capacity of 46.8 per cent as compared with 67.2 per cent in the case of the noneroded soil. At the same time the soil moisture which can not be absorbed by the root hairs of the plant, and which is therefore termed "non-available" water, was found to be 15.6 per cent in the eroded soil and 19.3 per cent in the noneroded soil. Owing to this the combi-

nation of higher water-holding capacity and higher percentage of available water when the soils are saturated there remains for the plant 16.7 per cent more water in the noneroded than in the eroded soil.

Tables 8 and 9 and figures 4 and 5 summarize the results as to vegetative growth and the water requirements of field peas, native bromegrass, and cultivated wheat grown in the two soils. In the case of each of the three plants the table shows that a much greater amount of water was required for the production of a unit of dry matter in eroded than in noneroded soil.

TABLE 8.—*Pounds of water required by peas, bromegrass, wheat, and wheat heads per pound of dry matter produced.*

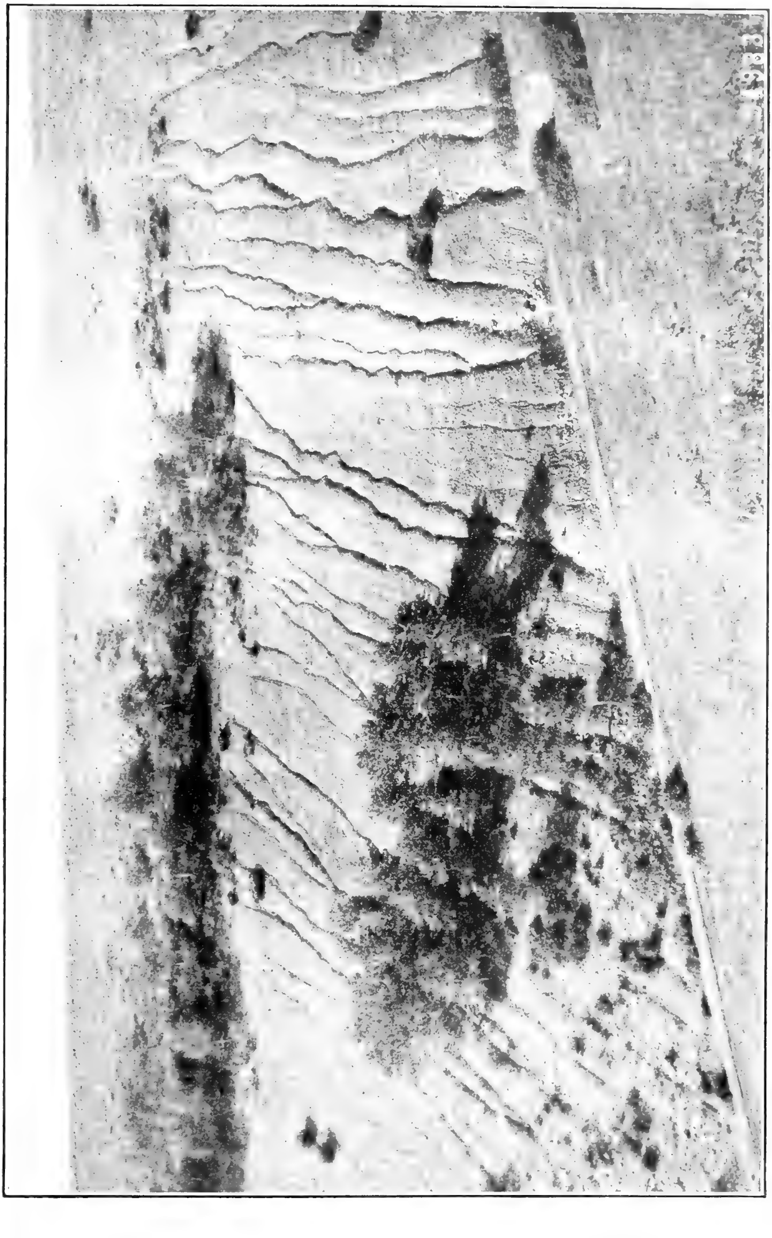
| Soil. | Peas. | Brome grass. | Wheat. | Wheat heads. |
|---|---|---|---|---|
| Eroded | 841 | 1,339 | 472 | 1,370 |
| Noneroded | 467 | 1,110 | 343 | 407 |
| Per cent difference | 80.3 | 20.6 | 37.6 | 2.66 |

TABLE 9.—*Summary of vegetative growth and water requirements of peas, bromegrass, and wheat.*

| Plant and soil. | Number of leaves. | Leaf length.[1] | Dry weight. | Water used per plant. | Water used per pound dry matter produced. |
|---|---|---|---|---|---|
| | | *Millimeters.* | *Pounds.* | *Pounds.* | *Pounds.* |
| Peas: | | | | | |
| Eroded soil | 42 | 791 | 0.79 | 667 | 841 |
| Noneroded soil | 712 | 2,634 | 6.55 | 3,051 | 467 |
| Native bromegrass: | | | | | |
| Eroded soil | 35 | 2,902 | .41 | 553 | 1,339 |
| Noneroded soil | 84 | 5,218 | .85 | 944 | 1,110 |
| Wheat: | | | | | |
| Eroded soil | 22 | 4,474 | 5.52 | 2,516 | 472 |
| Noneroded soil | 47 | 10,080 | 12.09 | 3,820 | 343 |

[1] In the case of peas the length of stem is given instead of the leaf length.

Figure 5, summarizing the vegetative growth and water requirement of peas on the eroded and noneroded soil, shows a remarkable contrast in the vegetative growth and other activities. The number of leaves is as 1 to 2.7; the leaf length, 1 to 3.3; the total dry weight produced, 1 to 8.3; and the water used per plant, 1 to 4.6, all in favor of the noneroded soil. In the water requirement per unit of dry matter, on the other hand, the ratio is reversed, being as 1.8 to 1 on the eroded and noneroded soils, respectively. Hence there are a great many more leaves, greater stem and leaf length, and more dry matter produced on the noneroded than on the eroded soil, with a notably smaller amount of water (Pl. IV). The latter fact, of course, is ac-



OVERGRAZING A COMMON CAUSE OF SOIL WASHING.

The original vegetation has been almost wholly removed as a result of too heavy grazing followed by drying and leaching of the soil. If grazing, especially of sheep, is not discontinued, revegetation can not be expected.


THE MEANING OF SOIL EROSION.

Canadian field peas (left) grown in poor or eroded soil and (right) in good mellow soil of the same type which has not been subjected to erosion.

counted for by the more luxuriant growth of the individual plants on the noneroded soil regardless of the smaller amount of water required for the production of a unit of dry matter.

In the case of native bromegrass and wheat the same behavior holds as to vegetative growth and other facts as in the case of the peas. Hence 2.4 and 2.1 times as many leaves of bromegrass and wheat, respectively, were produced on the noneroded as on the eroded soil; the leaf length, dry matter, and water used per plant

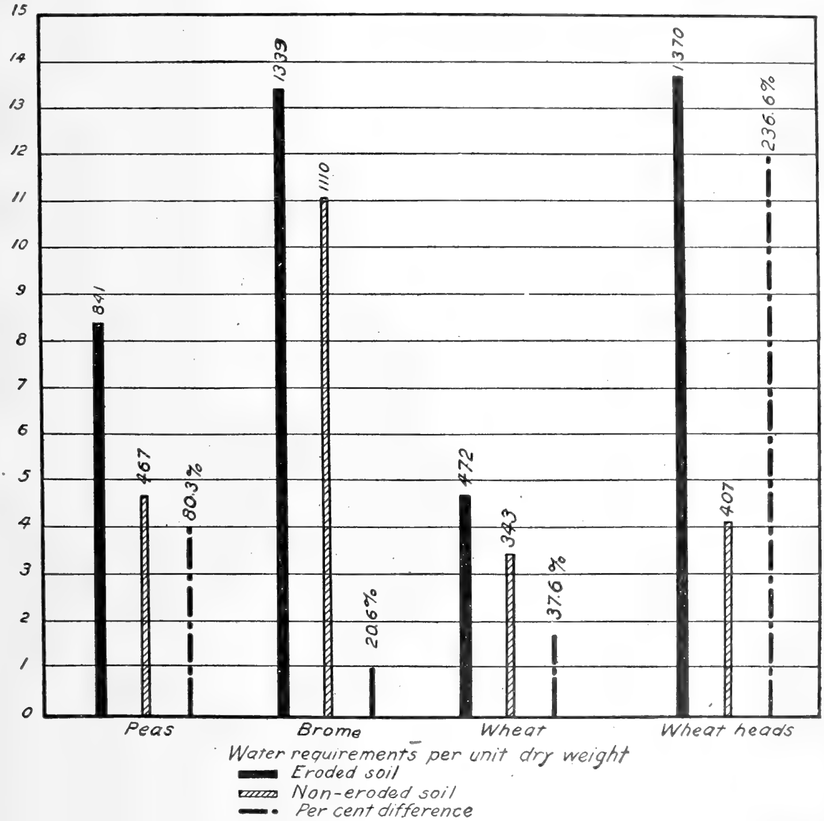



FIG. 4.—Relative water requirements per unit dry weight for peas, native bromegrass, and wheat grown in eroded and in noneroded soils of the same type.

were greater on the noneroded soil by 0.8 and 1.3, 1.1 and 1.2, 0.7 and 0.5 for native bromegrass and wheat, respectively. And here, again, the water requirement per pound of dry weight was greater on the eroded soil by 20.6 per cent and 37.6 per cent for the native bromegrass and wheat, respectively.

Erosion is detrimental to plant growth chiefly because it brings about the two following conditions of soil impoverishment: (1) Lack of adequate soil moisture for the full development and seed

production of the vegetation due to the lowered water-holding capacity of the soil, and (2) lack of adequate plant nutrients in the soil for good growth due to reduction of the soluble plant foods.

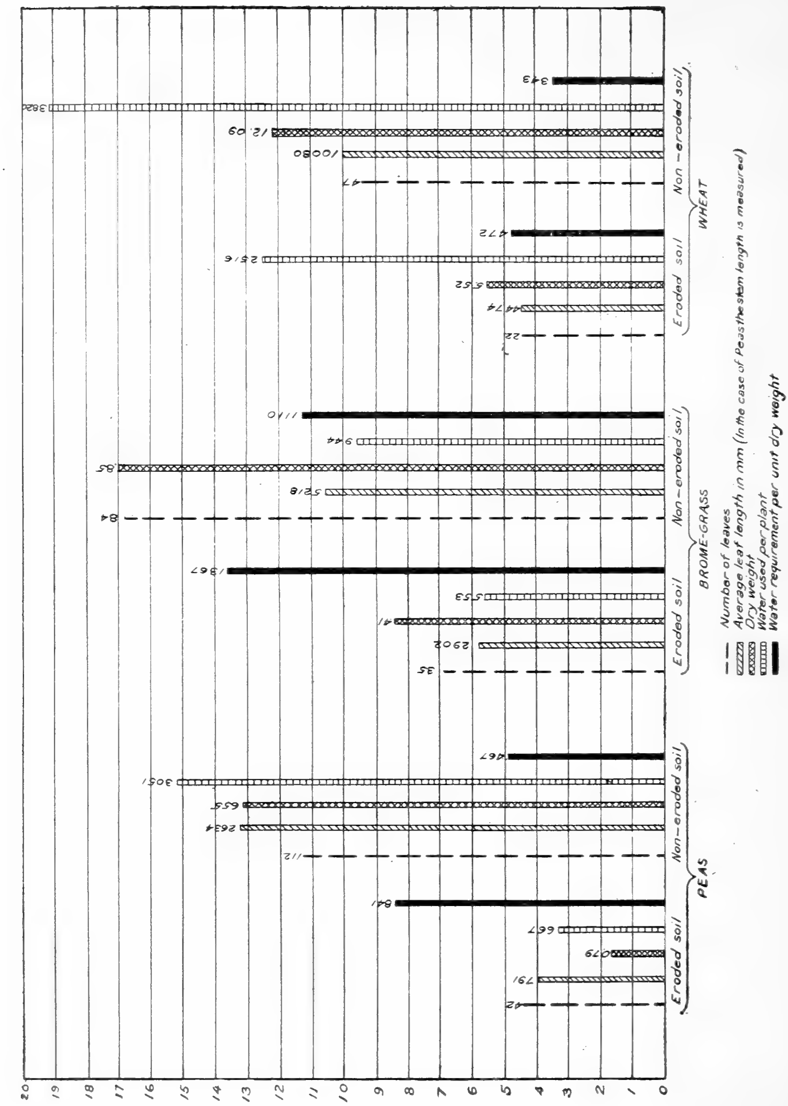



FIG. 5.—Summary of vegetative growth and water requirement of peas, native bromegrass, and wheat in eroded and noneroded soils.

## RELATION OF EROSION AND SOIL DEPLETION TO REVEGETATION.

The establishment on eroded soils of a dense vegetative cover made up of desirable forage and other deep-rooted, soil-binding species, similar to the original type, is a most difficult task. In the first place,

owing to the low moisture content due to exposure and lowered water-holding power, seed germinate poorly. Moreover, about nine-tenths of the plants which do come up die early in the spring while still in the seedling stage. The remainder usually dry up before the end of the season.

Interesting contrasts have been recorded on the mountain ranges of the Manti National Forest as to the rate of revegetation and the character of species being established on overgrazed and subsequently eroded lands as compared with lands which have not been seriously overgrazed, and where the soil, therefore, is relatively productive. During observations extending over four years (1913–1916) it was most exceptional to find on the more seriously eroded soils an increase in the number or appearance of new deep-rooted perennial species of any kind. On the less seriously eroded soils, on the other hand, shallow-rooted perennial species, both seedlings and matured specimens have gradually increased in number each season; and on somewhat overgrazed, but not eroded lands, deep-rooted perennials have increased relatively rapidly and steadily.

On analyzing the data recorded as to the rate and character of the revegetation it was found that by noting the seriousness to which the soil has been eroded, and hence its physical condition, including the relative amount of organic matter contained in it, it is possible to predict with much precision not only the rate at which the ground cover may be restored but the particular kind of plants that will occupy the soil for a temporary period prior to establishment of a permanent vegetation. As a general thing, many years must lapse before the more desirable forage species can reoccupy the site upon which they formerly predominated. The reestablishment of the deeper-rooted perennial species, if this type of vegetation is desired, and it usually is, can be accomplished on these eroded soils under range conditions only by certain rather inconspicuous plants first gaining a foothold on the land and gradually reinstating the vegetable matter and plant foods which are invariably lacking.

The replacement of one set of plants by another through a series of successive invasions is known as plant succession. Where the fertility of the soil has been seriously impaired only rapidly growing and early maturing annual species first occupy the soil. Several species of this type of vegetation begin germination and growth promptly in the spring, and before the soil has dried out to a point where the vegetation wilts beyond recovery and further growth, the plants have developed fully and ripened an abundant seed crop of good germination strength. The ramifications of the roots of these inferior plants through the soil season after season, the aeration of the upper soil layer as a result of the innumerable penetrations

and subsequent decay of the roots; and the addition of humus to the soil by the decomposition of the portions of the plant developed both below and above ground, finally accomplish wonders in improving the physical and chemical condition of the soil, provided, of course, that serious erosion in the meantime has been checked.

As the soil is improved and absorbs and retains more water than in the beginning, the annual plants develop more luxuriantly. At this point, however, the space occupied by the annual species is gradually encroached upon by slightly deeper-rooted, more robust annual plants, usually accompanied by a few shallow-rooted biennial and perennial plants. As the fertility of the soil is further improved, even the more robust annual species disappear and the more permanent perennial type of vegetation predominates as formerly. For many years after the latter type becomes conspicuous, however, less forage is produced, and of a poorer quality for stock generally, than before the soil became depleted.

From the above facts, then, it is evident that soil depletion, as related to forage production and revegetation, does not imply merely a temporary change in the character of the vegetation and nutritiousness of the forage; on the contrary, the time element enters as a highly important consideration. To reestablish completely the more desirable and permanent species, such as occupy the soil before it becomes depleted, often requires years of time coupled with expert management. Too much care can not be exercised by the stockman and farmer in preserving the dark surface layer of soil, for that portion is the very life of any land. Preserving the surface soil in the first place is much cheaper than replacing it, and this is not a difficult matter if proper precautions are taken when incipient erosion becomes apparent.

## INFLUENCE OF GRAZING ON EROSION AND STREAM FLOW.

While it is evident that the extent of run-off and erosion are roughly proportionate to the effectiveness of the ground cover in binding the soil, other factors being equal, the question as to whether run-off and erosion are augmented or retarded by grazing is one upon which opinions vary widely. Some stockmen contend that if a soil is cut up more or less by the trampling of stock, or the surface pretty thoroughly pulverized, more water will be held and subsequently absorbed by the soil than if the surface is undisturbed. Others are of the opposite opinion, contending that the packing of the soil, which unavoidably results from grazing, especially if the soil is fairly moist when stock travel over it, prevents the rain from being absorbed in maximum amounts. In carying out the details of the experiment on

the selected areas, strikingly significant results as to the effects of grazing and nongrazing were obtained.[1]

On July 21, 1915, when both areas had been protected from grazing since August, 1914, a heavy rainstorm occurred in which area B received approximately twice as much precipitation as area A; but only about one-twelfth as much run-off and one-ninth as much erosion was recorded from area B as from area A. On August 5, 1916, area B was grazed closely by sheep, area A being at that time ungrazed. Late in the day of August 5, a rainstorm occurred in which both of the selected areas received an average of 0.25 of an inch of rain. Practically the same amount of run-off was recorded

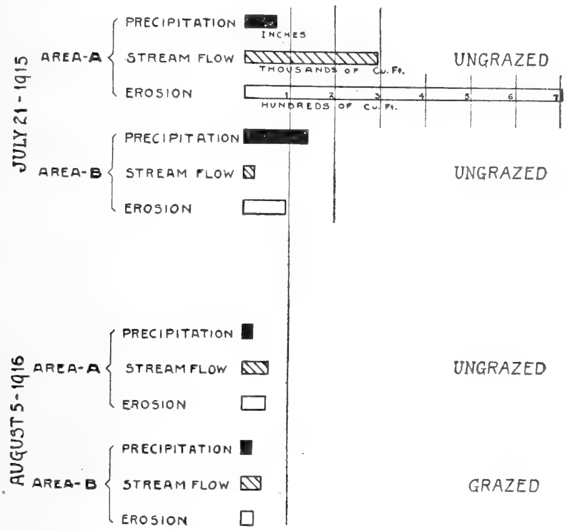



FIG. 6.—Relation of grazing and nongrazing to erosion and run-off.

from the two areas, and the erosion from area B was one-half that from area A, as shown in figure 6.

It will be noted, then, that the ratios of precipitation, run-off, and erosion on area B as compared with area A were changed from 2/1, 1/12, 1/8, respectively, to 1/1, 1/1, 1/2, respectively, as a result of grazing area B and not area A. Since grazing was the only factor changed as compared with all previous records, it appears safe to

[1] The grazing of the areas was carried out as follows: Both pastures were grazed moderately close by sheep at practically the same time in the season in 1914–1916, inclusive. The prescribed time for cropping the areas is when the forage is sufficiently developed to afford good grazing, a time which corresponds fairly closely to the grazing of the unprotected adjacent range. In case the ground is sufficiently wet to injure the vegetation seriously by trampling, or to cause harmful packing of the soil, grazing is deferred until a later date when soil conditions are normal. A band of sheep of the average size—about 2,500 head of ewes and lambs—is grazed on the areas. The sheep are allowed to graze at will, being worked over the pasture only to the extent of assuring uniform cropping. The vegetation is grazed closely but by no means destructively, the grazing corresponding in this particular to that on the adjoining range.

conclude that the change in the ratios of run-off and erosion showing a marked increase in erosion on area B was due to grazing. Instead of a large proportion of the rain being absorbed, the soil surface on area B was so hard-packed by the trampling of the stock that the run-off was appreciably increased. Much of the sediment deposited was carried directly from the gullies, a large amount of loose dirt having been worked into these depressions as the sheep traveled over them.

The example of increased erosion due to grazing as given on the selected areas under date of August 5, 1916, is merely an exact measurement of a condition which has been observed in many other cases. Excellent examples of results of varying intensity of grazing and of protection of the lands from stock have been observed on two adjoining watersheds on the Manti Forest. Until 1904 Manti Canyon flooded oftener—and the floods did more damage—than perhaps any other canyon on the entire Forest. From 1904 to 1917 this canyon has been grazed very lightly by cattle, while the adjoining canyons have been grazed fairly heavily each season. Though there is still abundant evidence of past erosion and innumerable gullies at the head of the Manti watershed, the gullies have rounded out and the soil, having assumed an angle of repose, now supports a stand of grass and weeds. The fine soil, with its increased organic matter, is so loose and mellow that a saddle horse sinks into it over his hoofs. At the head of Becks Canyon, 3 miles north of Manti Canyon, sheep have grazed each year. Instead of a loose soil it is hard-packed, the gullies are relatively deep and V-shaped instead of rounded, and they support practically no vegetation either on the sides or bottom. Each of these watersheds has been under observation during various rainstorms and the amount of precipitation received at the head of each canyon has been recorded by means of rain gauges. A rainstorm that is completely absorbed without surface run-off on the Manti drainage often produces innumerable muddy rivulets in a few minutes on the Becks Canyon drainage. It would take a very heavy rainstorm—considerably heavier than has occurred during the past eight years—to produce a flood in Manti Canyon. From Becks Canyon, on the other hand, floods have occurred as a result of 0.55 of an inch of rainfall; several floods have originated in this canyon during the past few years.

Another instance showing the relation of grazing to erosion and floods occurred August 2, 1912, in Twelve Mile and Willow Creek Canyons. A committee of sheepmen, cattlemen, and Forest officers who were inspecting the range in Twelve Mile Canyon on the day of the storm which occasioned the flood testified that these floods came from mountain areas adjoining the Manti Forest which had been used as lambing grounds for several successive years. The ob-

servers stated that the storm was uniform over the areas under protection in the Forest and on the adjoining grazed area. The small amount of run-off that occurred on the protected lands was clear and the streams were little more than normal in size; the flow from the unprotected and heavily grazed areas tore out bridges and roads and was laden with bowlders, mud, and débris. As a result of the inspection, the committee requested that the areas from which the floods originated be made a part of the Manti Forest and that grazing be discontinued until the vegetative cover could be restored.

From the above data and general observations there can be no doubt that the moderate grazing of sheep on the relatively sparsely vegetated range upon which the topography, climate, and soil are favorable to erosion and upon which erosion is at least in the incipient stage, will appreciably increase both the run-off and erosion. This increase for a given area will vary according to the closeness with which the lands are grazed and the particular methods of handling the stock. It is evident that once the vegetative cover has been broken up and the soil laid bare, grazing tends to promote rather than to retard run-off and erosion.

## PREVENTIVE AND REMEDIAL MEASURES.

### MAINTENANCE OR RESTORATION OF THE VEGETATIVE COVER.

The need for maintaining the vegetative cover at all times in order to prevent destructive floods and erosion, and the importance of placing the live-stock industry on a substantial, permanent basis, both so far as concerns the range forage crop and the marketing of the farm products through live stock, has been shown. It remains now to show how and to what extent the vegetation may be utilized by live stock year after year without serious destruction of the vegetative cover. The maintenance of a maximum cover of vegetation and continuance of grazing are naturally antagonistic at best, and unless certain recognized principles of range and live-stock management are put into practice there is danger of impairing the ground cover.

#### AVOIDANCE OF OVERGRAZING.

The first precaution is to avoid overgrazing, which can best be accomplished by accurately estimating and then adjusting the number of live stock a range unit or allotment will safely carry. Excessive grazing will first show itself in the weakened condition or disappearance of the choicest and most palatable forage plants. This is usually accompanied by the appearance of incipient gullies, followed by erosion of varying seriousness. If the carrying capacity of the lands is promptly adjusted so that there is ample feed for the stock throughout the season, the vegetative cover, provided the lands and stock are otherwise properly managed, should be maintained indefinitely.

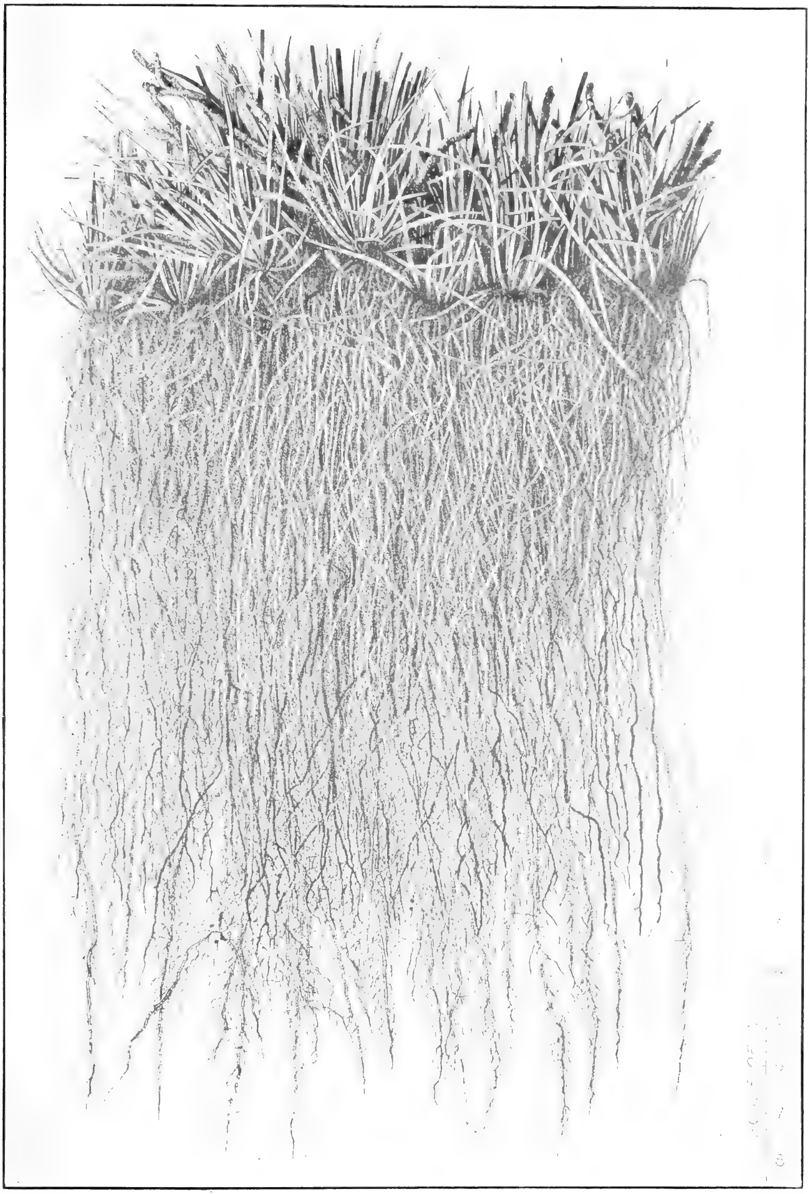
### AVOIDANCE OF TOO EARLY GRAZING.

One phase of mismanagement which is often overlooked by the stockman and which is responsible for serious destruction of the vegetation, is that of permitting stock on the range too early in the spring, when the herbage is very young and succulent, and when the soil is well-nigh saturated with moisture. A week to 10 days after growth starts in the spring the forage has very little "substance" and is rather deficient in sugars and protein as compared with forage which has been growing twice as long. At no time in the season is it more essential that a plant be permitted to develop its leafage, which is the laboratory for the production of food, than early in the spring. A few days' delay in the time of grazing following the inception of growth will not only insure the production of a much larger forage crop for that particular season but in subsequent seasons as well, and the herbage will have much more strength and fattening qualities. Then, too, the bad effects of trampling over the loose, wet soil is largely avoided and the exposure of the roots and subsequent drying out of a large proportion of seedling forage plants is prevented.

### THE PRACTICE OF DEFERRED AND ROTATION GRAZING.

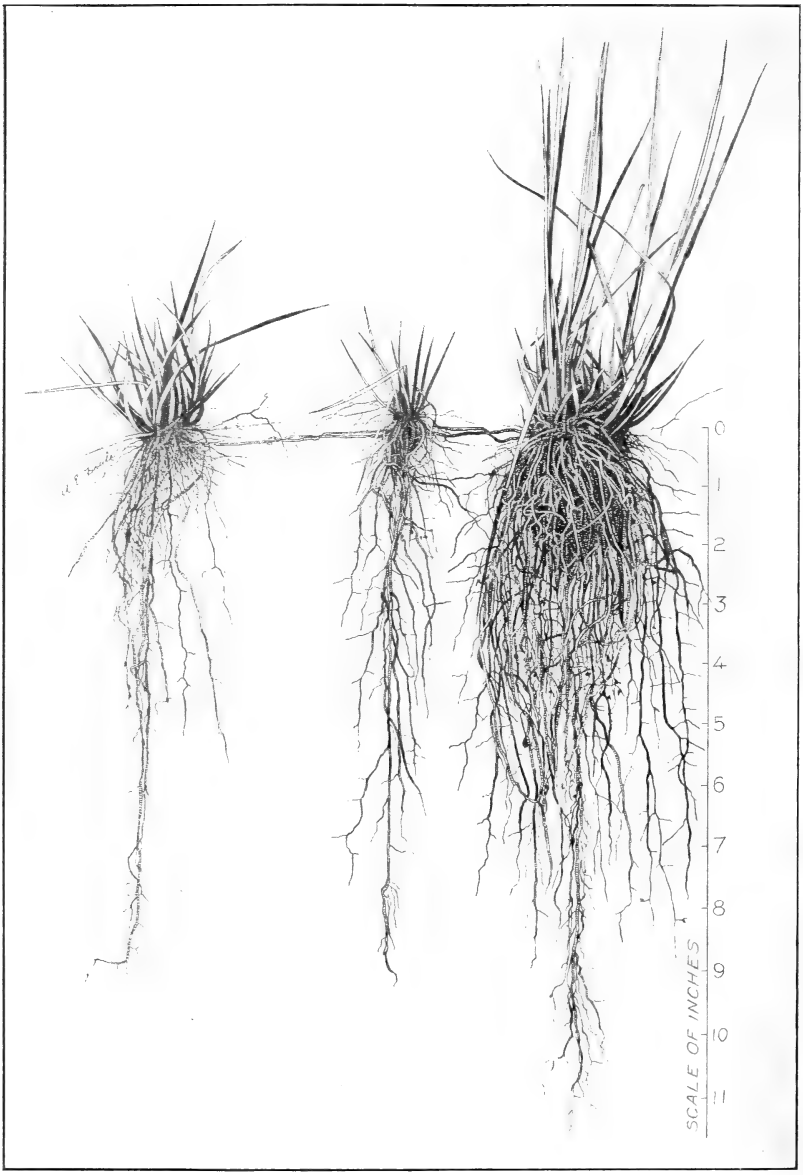
In the case of virgin range lands there will be no difficulty in maintaining indefinitely the vegetative cover provided the lands are not grazed beyond their actual carrying capacity and too early in the spring. But where the range has already been overgrazed and the original ground cover considerably thinned out, but not all of the seed plants destroyed, merely keeping the number of stock down to the estimated carrying capacity and preventing too early spring grazing are not in themselves effective means of reestablishing the desired vegetative stand. In such instances deferred and rotation grazing must be applied.

In applying the deferred system of grazing, such portion of the range as is consistent with the welfare of the range as a whole is reserved for cropping until after the maturity of the seed of the main forage species. Upon the maturity of the seed the range is grazed closely, but not destructively, by the stock allotted to the lands. The following year, owing to the large proportion of seedlings destroyed, especially on areas grazed early in the season, the forage is not to be cropped until another season's seed has been produced. If, after the production of two seed crops of the choice native forage species, an ample number of seedling plants have been established, a second area in need of seeding is selected and the tract upon which grazing was previously deferred is then grazed before seed maturity. This same plan is continued season after season, alternating the de-



TURF-FORMING GRASSES BIND THE SOIL FIRMLY.

Kentucky blue grass, where it thrives, affords excellent protection against soil washing. Being a turf-forming grass it protects the soil surface uniformly well.




UNDERGROUND PARTS OF A YOUNG GRASS.

Slender wheat grass commonly reproduces vegetatively and sends up shoots at varying intervals. Though it is a bunch grass, this species is a good soil binder.

ferred grazing first on the one area and then on another, until the entire range has been rejuvenated. After the vegetative cover has been established, however, the deferred grazing is alternated or rotated from one portion of the range to another in order to permit of the formation and distribution of an occasional seed crop by means of which the old plants may be replaced. In this way the range is brought back and maintained in its maximum state of productivity without the loss of a season's forage crop during the period required for revegetation.

### ARTIFICIAL RESEEDING.

The lack of fertility and moisture in eroded soils, as pointed out, makes it necessary first to build up the depleted lands before even the most drought-resistant, well-adapted native perennial species can be reseeded. Cultivated forage plants, even of the most drought-resistant kinds, are more exacting in their requirements of plant foods and soil moisture than native species; consequently artificial reseeding can be recommended as a paying proposition only where the soil of mountain range lands is above average in fertility and where the moisture conditions are favorable to growth throughout the summer season. Incipient meadow erosion may in some instances be held back by seeding to cultivated plants of a soil-binding type, like Kentucky bluegrass, but under such conditions the scattering of a little seed of aggressive, turf-forming native species on the exposed soil is still better. (See Pls. V and VI.)

### CONTROL AND DISTRIBUTION OF LIVE STOCK.

One of the most common causes of range depletion, even where the carrying capacity of the lands as a whole has been carefully estimated, the season of grazing adjusted, and the deferred and rotation system of grazing adopted, is the excessive grazing of one area and the nongrazing or very light cropping of another as the result of poor distribution of stock, improper salting, and faulty handling of the stock, especially sheep.

There is a tendency among cattle and horses to drift to and congregate on the more elevated plateaus, though the feed may be at its best at lower elevations. While they may not reach the mountain ranges for some time after growth has started, far more animals may remain on certain lands than can be grazed without injury to the vegetation. In the meantime the forage at lower elevations dries up and becomes less palatable, the temperature becomes too high for the stock to make maximum gains, and as a consequence much of the forage is wasted.

The most effective means of holding cattle and horses on the portion of the range desired, and at the same time obtaining even distribution, are properly located salting and watering places and drift fences. The salting places can be located in such a way as to compel the animals in search of salt to travel over the range lands desired. This, of course, is also true of the location of places where water is to be developed for live-stock purposes, though, of course, the latter is much more difficult to control than is the distribution of salting places. Likewise, under certain conditions, drift fences constructed in suitable places are the most effective means of protecting the range from excessive grazing and undue trampling by stock.

In the case of sheep two conditions (aside from overestimating the carrying capacity of the lands) are chiefly responsible for the destruction of the vegetative cover, (1) bedding too long in one place, and (2) too close herding and the excessive use of dogs.

Bedding sheep several nights in one place necessitates trailing to and from feed to such an extent as to uproot and destroy much of the ground cover. In addition, the bed ground itself is completely denuded of vegetation and years are required fully to reestablish the stand.

Trailing back and forth from range to an established bed ground should be replaced by the "burro" or "blanket" system of herding, that is, camping wherever night overtakes the band. Numerous sheep raisers who have abandoned the use of the regular bed ground would never think of going back to the practice, for the reason that the feed is infinitely better than formerly and because appreciably larger gains are made by the sheep. When no regular bed ground is used and the sheep are given all the freedom possible consistent with the grazing of suitable range, the band is more content and easier to handle and there are less losses from poisonous plants. At the same time the all-important ground cover is not destroyed, provided the "leaders" and "laggers" of the band are not excessively dogged and roughly handled. Often as much vegetation is destroyed through the excessive use of dogs as from overgrazing and subsequent run-off.

On lands where the sum of conditions favoring floods and erosion—such as deficient vegetative cover, steep slopes, and the presence of numerous gullies of the incipient and advanced type exist—it is the safest plan to undergraze rather than utilize the herbage so closely as possibly to injure the existing vegetation. In general, greater injury is done on such lands by trampling than by actual grazing; consequently, unless the range is excessively rough and irregular, it is often a distinct advantage to graze the lands by cattle rather than by sheep.

## REMEDIAL MEASURES WHERE THOROUGH REVEGETATION BY ORDINARY MEANS IS IMPOSSIBLE.

### TOTAL EXCLUSION OF STOCK.

On the more important fan-shaped basins at high elevations, where the original vegetative cover, including the seed plants, has for the most part disappeared, and where the fertility of the soil has been seriously depleted as a result of erosion, the best plan is to discontinue grazing entirely. The small amount of forage produced, consisting, as it usually does, of annual weeds and many poisonous species, by no means compensates for the further skimming off of the already deficient organic matter and tearing down into the gullies of the loose soil. In most instances stock will not have to be excluded longer than during the period required to reestablish the fertility of the soil and the incoming of the deep-rooted, permanent type of perennial vegetation, provided, of course, that light grazing and proper handling of the stock are at all times resorted to. On the other hand, where the soil fails to regain its former productivity within a reasonable length of time, as indicated by the character and density of the vegetative cover following the exclusion of stock, grazing should be permanently discontinued. To graze such lands after a few years of rest, even though they produced a little feed, would be to undo in a season all that nature has accomplished in building up the soil during the seasons that stock was excluded.

### TERRACING AND PLANTING.

There are local areas, mostly of small size, where the proper regulation of grazing and, indeed, the total exclusion of stock from seriously eroded lands is delayed until the vegetative cover can not be effectively reestablished and the erosion thus eliminated. The establishment of a dense cover of vegetation should not be hoped for on the bottom and along the sides of deep, vertically cut gullies where the water rushes by after each rainstorm of appreciable size. The force of the water does not permit many seeds to lodge, and in the beginning the soil is too thin and dry to favor growth. Depressions of the more prominent gullies which have been revegetated, however, would still serve as drainage channels following heavy rainstorms, but the resistance afforded by the vegetation would tend to hold the water back; and since the soil would be held firmly by the roots, the channels would tend to flatten out rather than become more prominent.

Where it is no longer possible for the vegetation to hold the soil intact, some means of artificial control is necessary. The gully

systems can usually be effectively broken up by the construction of terraces laid out approximately at right angles to the gullies but so placed as to allow water to be carried through their channels. If reinforced by small rock fills built into the washes at sufficiently frequent intervals to check the run-off before the cumulative effect of the water's force becomes uncontrollable, the terraces appear to be effective.

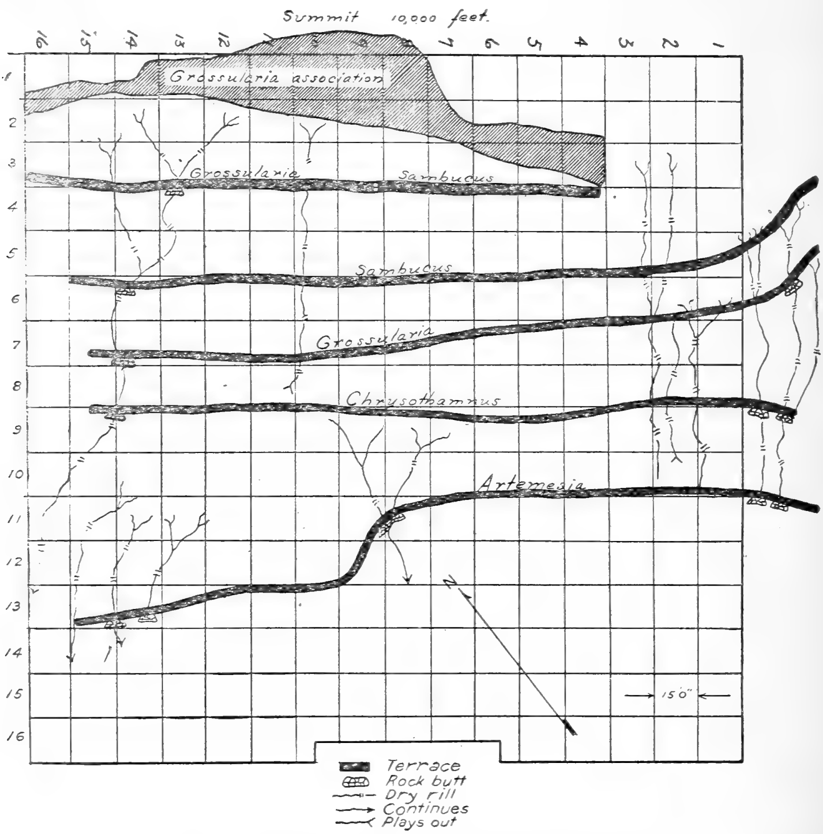



FIG. 7.—Tree and shrub planting to check erosion.

The place of successful attack of an evil like the one in question is at the origin of its source. In order thoroughly to test the value of terraces located near the heads of the gullies and planted to soil-binding species, a badly gullied area was selected on a southwest slope at an elevation of approximately 10,000 feet. This study is still in an experimental stage. As shown in figure 7, the distances between the terraces which were established vary considerably, being determined by the number of gullies and other topographic features.

In establishing a terrace, strips are plowed about 4 feet wide, or even wider on the steeper slopes, following which the loosened soil

is smoothed out by means of a homemade terrace drag (fig. 8). The drag is constructed in a V-shape and can be made any width provided the proportions are followed as given in the sketch. In order that the drag may work effectively one or two men usually stand on the crosspiece supporting the side beams. As soon as the terrace is well smoothed it is ready for planting.

Planting early in the spring before growth has started has given the best results; and since the soil can not be worked satisfactorily at that time terraces can best be established in the autumn. At the intersection of the more prominent gullies and the terraces, the former are built up with rock butts and overlaid with soil. In order to hold the terrace soil as effectively as possible, the terraces are planted to such soil-binding species as wild gooseberry (*Grossularia*), mountain elder (*Sambucus*), yellow brush (*Chrysothamnus*), sweet sage (*Artemisia*), yarrow (*Achillea*), and several species of sub-

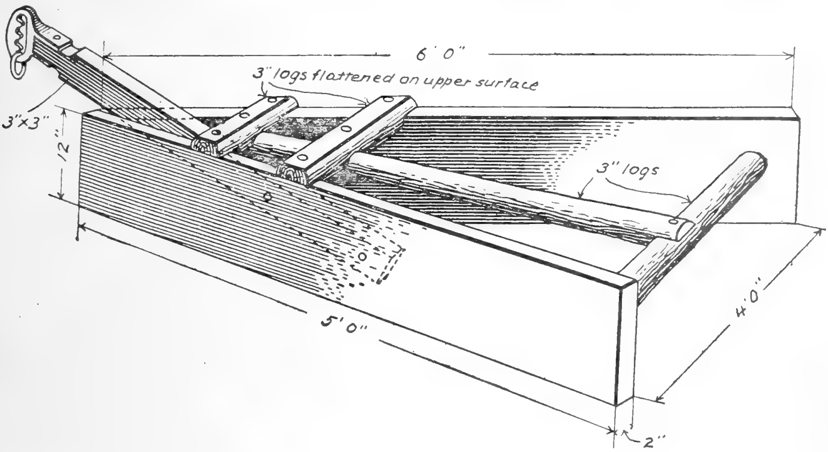



FIG. 8.—Terrace drag.

alpine grasses. Since seed of native grasses, which soon become firmly established on the terraces, can not be purchased from commercial seed houses it has been necessary to collect seed wherever a good crop developed naturally. However, following the establishment of the terrace a great deal of seed of native species is caught during the natural seed dissemination period in the autumn, and in two seasons or so the terraces become fairly well vegetated. As the soil is enriched through the accumulation of decayed vegetable matter, conditions for growth are gradually made more favorable and the vegetation develops luxuriantly.

The area experimented with, prior to the establishment of the terraces and fill work, had been subject each season to serious erosion. Since the establishment of the terraces and supplemental work, no erosion whatsoever has occurred and the lands are generally becoming

revegetated. The establishment of terraces and subsequent planting to suitable native species, therefore, offers considerable promise on lands that have eroded to such a point that revegetation is extremely slow and the subterranean parts of the vegetation uneffective in binding the soil and in preventing erratic run-off. The cost of the establishment of terraces will vary greatly according to the depth and number of gullies and the amount of fill work necessary. Where a moderate stand of native vegetation occurs within the vicinity of the terraces it will not be necessary to plant directly, provided a satisfactory seed crop is produced.

### CONSTRUCTION OF DAMS.

In various parts of Europe, notably in the Swiss Alps, and to a less extent in this country, elaborate earth, stone, and concrete dams have been constructed where the less expensive contour terraces are inadequate in preventing continued destructiveness from erosion in critical localities. Obviously, the construction of elaborate dams is expensive and their use is limited to situations where the destruction to personal and other property is of much more than average seriousness. Problems of this character properly fall under the scope of engineering.

### SUMMARY OF PREVENTIVE AND REMEDIAL MEASURES.

The maintenance of an effective vegetative cover may be accomplished by the following means:

1. Avoidance of overgrazing.
2. Avoidance of too early grazing.
3. Deferred and rotation grazing.
4. Artificial reseeding (in choice sites only).
5. Proper control and distribution of stock.

Where the depletion of the soil and the formation of long established gullies make thorough revegetation impossible, destructive floods and erosion may be controlled in the following ways:

1. Total exclusion of stock.
2. Terracing and planting.
3. Construction of dams.

## CONCLUSIONS.

1. Erratic run-off and erosion have been responsible for a great deal of damage on western ranges where the vegetative cover had previously been materially decreased or practically eliminated.

2. Though the damage from erosion usually is measured merely by the injury caused to farm land and works of construction, the damage to the forest range lands upon which erosion occurs is often

greater and shows itself in decrease in carrying capacity of the lands.

3. While topography, climate, and soil are the primary factors in determining erosion, the combination of these factors on the lands under consideration is such that erosion is slight where the native ground cover has not been greatly disturbed. The seriousness of the erosion, therefore, is largely determined by the extent to which the ground cover is maintained.

4. Serious erosion on western range lands is due chiefly to the destruction of the vegetation as a result of overgrazing and mismanagement of live stock.

5. The sum of conditions favoring destructive run-off and erosion is most pronounced in the fan-shaped drainage basins of the spruce-fir type (on the Manti National Forest between 9,000 and 10,500 feet), where the ground cover is naturally rather sparse, where there is a characteristic sparseness of tree growth. and where the most desirable summer sheep ranges are located.

6. To maintain an effective vegetative cover, overgrazing and too early cropping of the herbage must be avoided, deferred and rotation grazing should be applied, and stock should be properly controlled and distributed at all times in the season.

7. In the case of incipient erosion, only slight changes in the use of the lands are generally necessary, and these changes do not necessarily imply even a temporary financial loss.

8. Where erosion has had full play for a number of years, the reestablishment of the ground cover, even though grazing is discontinued, does not always afford adequate protection. In such instances, which fortunately are relatively rare in this country, a combination of terracing and planting or, in exceptional cases, the construction of dams is justified.

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